phosphate and water, expressed as microatoms of oxygen transferred per milligram of protein per hour. The exchange rates proved to be the same order of magnitude. In several instances we simultaneously measured the rate of oxygen metabolism and observed comparable values. Whole as well as broken cells of the bacterium *Hydrogenomonas* showed a correlation between the rate of exchange and metabolic activity, that is, the availability of metabolic substrate. Disruption of the cells by sonic treatment prior to incubation tended to stimulate activity, which could be retained during storage of the preparations in the lyophilized form.

Table 1 lists exchange between nitrate or phosphate and water, catalyzed by randomly collected soil samples. With one exception, the data in this table were collected with a simple, single-collector mass spectrometer instrument; nevertheless the exchange was clearly measurable. Relatively few experiments have been made with nitrate: these indicated a seasonal variation in soil activity, and generally gave positive results, often exceeding those obtained with phosphate. Figure 1 shows the time course of exchange catalyzed by a soil sample of low bacterial count. These data were obtained with the more sensitive double-collector duplex inlet instrument. In this case an unambiguous indication was obtained in less than 10 hours. The time course shows the more-or-less expected response of microbial activity upon moistening this soil with a 0.1*M* solution of phosphate. So far our experiments have been exploratory and restricted to the two anions discussed. As it stands (see Table 2), we can assume the limit of detection (for $\Delta R = 0.05$ percent) to be $\sim 10^4$ organisms per gram of soil or 10^3 organisms per 0.1-gram sample in 24-hour incubation.

Tremendous amplification of the exchange rate is obtained by growth which can be induced by adding appropriate nutrients. Since the advantage of the proposed method is that it does *not* require growth or depend upon close similarity to terrestrial biochemistry, its uniqueness would be defeated by such additions, unless they could be extracted from Martian soil or were selected to provide specific answers concerning the metabolic activity detected.

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References and Notes

1. *Life Sciences and Space Research (COSPAR)* (Wiley, New York, 1963–65): vol. 1, R. B. Livingston, A. A. Imshenetsky, G. A. Derbyshire (1963); vol. 2, M. Florkin and A. Dollfus, Eds. (1964); vol. 3, M. Florkin, Ed. (1965).
2. W. Vishniac, *Extraterrestrial Life*, E. A. Shneour and E. A. Ottesen, Eds., Natl. Acad. Sci.–Natl. Res. Council, Publ. 1296A (NAS–NRC, Washington, D.C., 1966), p. 282.
3. M. Cohn, *J. Biol. Chem.* **230**, 369 (1958).
4. G. Hoch and B. Kok, *Arch. Biochem. Biophys.* **101**, 160 (1963).
5. H. C. Urey and C. R. McKinney, *Rev. Sci. Instr.* **21**, 724 (1950).
6. D. Kahn, *Research Institute for Advanced Studies Techn. Rep. 67-1* (RIAS, Baltimore, 1967).
7. M. Anbar and S. Guttman, *J. Amer. Chem. Soc.* **83**, 4741 (1961).
8. T. C. Hoering and J. W. Kennedy, *ibid.* **79**, 56 (1957).
9. C. A. Bunton, D. R. Llewellyn, C. A. Vernon, V. A. Welch, *J. Chem. Soc.* **1961**, 1636 (1961).
10. C. A. Bunton and G. Stedman, *ibid.* **1959**, 3466 (1959).
11. D. Pramer and E. L. Schmidt, Eds., *Experimental Soil Microbiology* (Burgess, Minneapolis, 1964).
12. Supported in part by NASA (NASw-747). We thank Drs. J. C. Medici, R. J. Owellen, and T. Wang, and Mr. J. Katzenellenbogen for their cooperation and suggestions in various aspects of this work.
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Splashing of a Water Drop

Abstract. *Measurements have been made of the number of spray droplets produced by the impact of a water drop on water, and of the charge to mass ratio for these droplets. For a drop 3 millimeters in diameter, the number of spray droplets increases linearly with the fall-distance of the drop over the range 10 to 200 centimeters. When the drop falls 100 centimeters, about 25 spray droplets are produced. The majority of the droplets carry a negative charge, and the ratio of the charge to the mass varies from 4 to 28 electrostatic units per gram.*

If a drop, several millimeters in diameter, falls from a height of about 30 cm into a liquid, the following sequence of events takes place (*1*). When the drop collides with the surface (Fig. 1a) a crater of liquid is thrown up which increases in height as the drop penetrates the surface. Small jets are shot out from the rim of this crater to form a "crown" of liquid (Fig. 1b; 0.003 second after Fig. 1a) and these break up to give numerous spray droplets (Fig. 1c; 0.003 second after Fig. 1b). As the walls of the crater thicken they begin to subside (Fig. 1d; 0.008 second after Fig. 1c) and the downward flow of liquid results in the ejection of a large column of liquid from the center of the crater (Fig. 1e; 0.026 second after Fig. 1d) which is known as the Rayleigh jet. The Rayleigh jet may pinch off to form one or more large drops (Fig. 1f, 0.030 second after Fig. 1e; and Fig. 1g, 0.002 second after Fig. 1f). Rayleigh (*2*) has explained this phenomenon in terms of the amplification of an unstable wave on the surface of the jet (Fig. 2).

The photographs also show that the drops thrown off from the jet oscillate as they fall through the air. The liquid used was a mixture of milk and water. Measurements from the photographs show that the period of vibration τ of a drop 3.6 mm in diameter is about 2.2×10^{-2} second. Rayleigh (*2*) has shown that in the case of small vibrations of a liquid drop

$$\tau = \sqrt{\left(\frac{3\pi\rho V}{8T}\right)}$$

where ρ is the density of the liquid, T the surface tension, and V the volume of the drop. The surface tension and the density of the mixture of water and milk were 50.5 dyne/cm and 1.014 g/cm^3. Hence, for a drop of diameter 3.6 mm, the theoretical value of τ is 2.4×10^{-2} second, which is in good agreement with the experimental result.

The spray droplets that are thrown out from the crown, and the drops from the Rayleigh jet, carry an electric charge. Lenard (*3*) observed that the air in the neighborhood of a waterfall, or a shower bath, has a negative space charge, and he attributed this to the splashing of the water drops. More recently, Pierce and Whitson (*4*) have measured the changes in the electric field in the vicinity of waterfalls in the Yosemite Valley and have verified Lenard's observations. However, few measurements have been made of the total number of spray droplets, or of the charge on individual spray droplets produced by the splashing of water drops on water. We here describe recent measurements of these two quantities.

Water drops were produced by passing distilled water under slight pressure through a 26-gauge stainless steel hypodermic needle. The pressure was adjusted so that the drops breaking away from the tip of the needle were 3 mm in diameter. After falling freely through a measured distance in air, the drops collided with distilled water contained in a vessel 10 cm in height

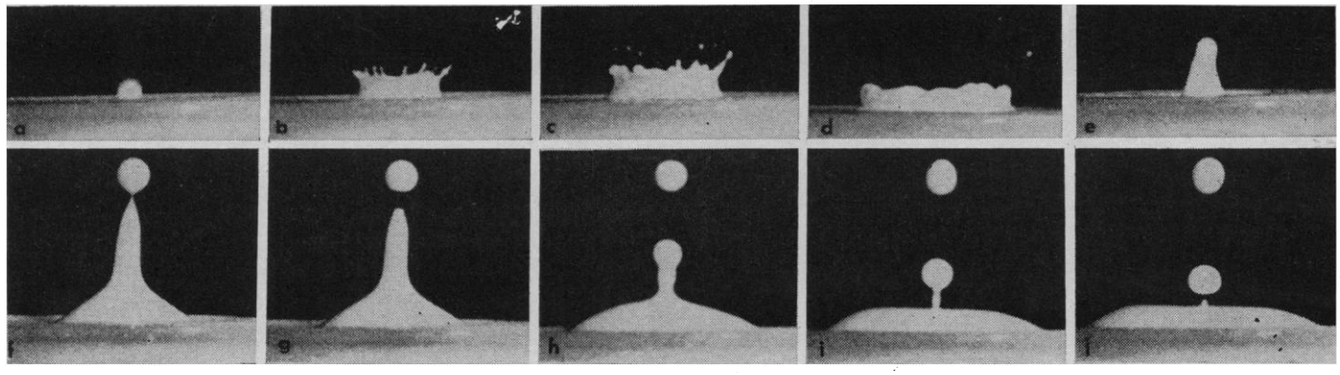

Fig. 1. The sequence of events following the impact of a drop approximately 3.4 mm in diameter on a plane surface of liquid (× 2.5).

and 5.6 cm in diameter. The number of spray droplets produced by a collision was measured with the aid of special paper sensitive to water, which was prepared by dipping filter paper into a solution of iodine and alcohol. After the paper dried it turned brown, but if water droplets landed on it white spots were produced. This paper was placed a few millimeters above the surface of the water and a small hole was made in it through which the drops could pass; the spray droplets could then be detected and counted by the white spots they left after colliding with the underside of the paper.

The number of spray droplets produced as a function of the distance that a drop 3 mm in diameter falls is shown in Fig. 3. No spray droplets were produced if the distance that the drop fell was less than about 10 cm. From 10 to 200 cm the number of spray droplets increased linearly with the distance of fall. It should be noted, however, that 200 cm is only about one-quarter the distance that a 3-mm drop must fall to reach its terminal velocity. Moreover, the extrapolation of the results shown in Fig. 3 to much greater distances of fall is probably invalid, for, as the impact velocity increases, the mouth of the crater closes to form a bubble on the surface of the liquid and the nature of the splashing process is modified (*1*).

The formation of the spray droplets, and the increase in their number as the distance that the drop falls increases, may be understood qualitatively. The situation is similar to that of the unstable amplified wave on the Rayleigh jet. However, in the case of the crater, waves will be propagated both in the vertical direction and along the circumference of the crater. As the amplitudes of these waves increase, the upper rim of the crater will become ragged and the crown will form. It seems reasonable to assume that the number of droplets thrown off from the crown will be determined by the interval of time that the crater remains above the surface. Since the height to which the crater rises increases as the distance that the drop falls increases, it follows that the number of spray droplets will also increase with the distance of fall. Moreover, when the distance that the drop falls is below a certain critical value, there will be insufficient time and available energy for any spray droplets to break away from the crown. We have seen that in the case of a drop 3 mm in diameter this critical distance is about 10 cm.

The ratio of the charge q to the mass m for individual spray droplets was determined by allowing the droplets to fall between two vertical and parallel plates across which an electric field E of 4000 volt/cm was applied. In order to avoid induction charging due to stray electric fields from the

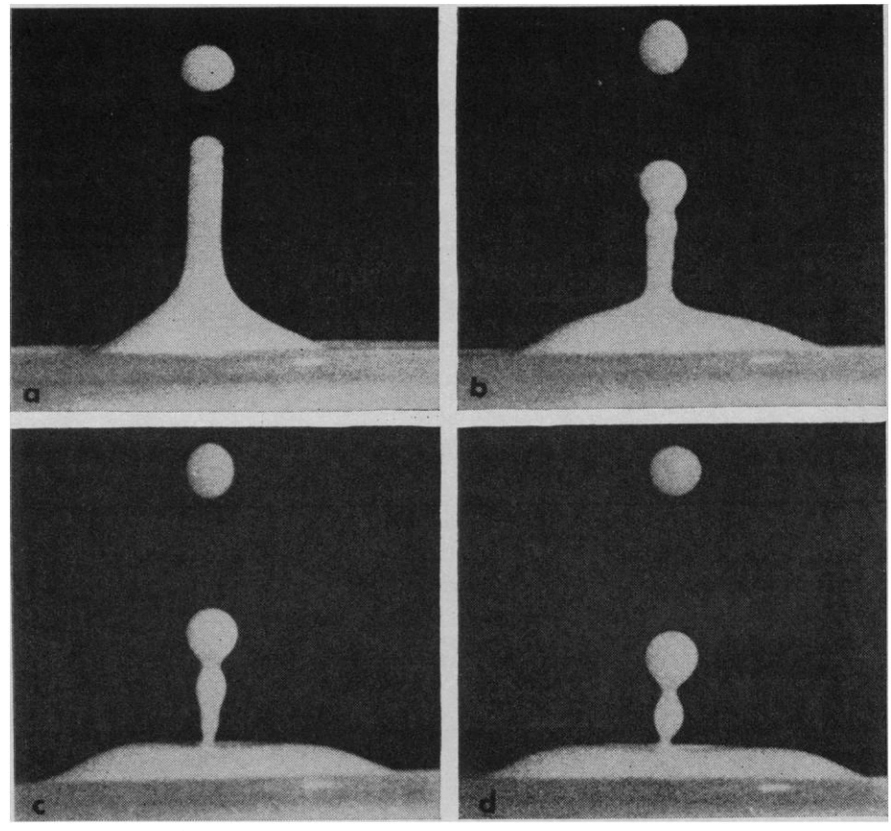

Fig. 2. The amplification of an unstable wave on the surface of a liquid jet. The time intervals between the photographs are 0.01, 0.006, and 0.005 second, respectively (× 2.5).

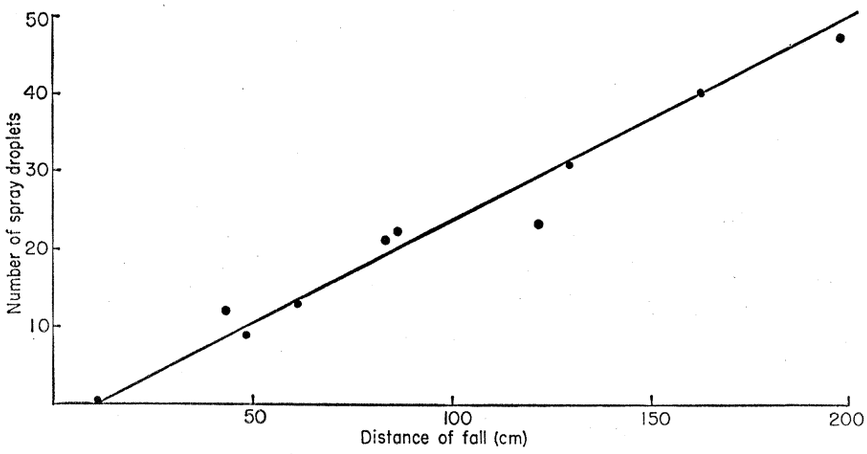

Fig. 3. Number of spray droplets as a function of the distance that a water drop 3 mm in diameter falls.

electrodes during the formation of the spray droplets, a grounded plate was placed between the water and the electrodes. The ratio of the charge q on a droplet to its mass m was determined from the formula

$$q/m = (g/E) \tan \theta$$

where θ is the angle which the path of the droplet makes with the vertical direction and g is the acceleration due to gravity. The angle θ was determined by photographing the path of a droplet in stroboscopic illumination as it fell through the electric field.

The direction in which the spray droplets were deflected in the applied field showed that nearly all of them carried a negative charge. The measured values of q/m varied from about 4 to 28 electrostatic units per gram. From estimates of the size of the droplets from the photographs, approximate values were obtained for the magnitudes of the charges on the spray droplets. The results showed that the larger droplets had the greater charge. For example, droplets 125, 200, and 400 μ in diameter had charges of 9.2×10^{-6}, 5.4×10^{-5}, and 9.4×10^{-4} electrostatic units, respectively. The distance that the drop fell, on the other hand, appeared to have little effect on the charges carried by the spray droplets over the range investigated.

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References and Notes

1. A. M. Worthington and R. S. Cole, *Phil. Trans. Roy. Soc. London Ser. A* **180**, 137 (1897); *ibid.* **194**, 175 (1900).
2. Lord Rayleigh, *Proc. Roy. Soc. London Ser. A* **29**, 71 (1879).
3. P. Lenard, *Ann. Phys. Leipzig* **46**, 584 (1892); *ibid.* **47**, 463 (1915).
4. E. T. Pierce and A. L. Whitson, *J. Atmospheric Sci.* **22**, 314 (1965).
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Loss of Thymus-Distinctive Serological Characteristics in Mice under Certain Conditions

Abstract. *The serological properties of thymus cells of inbred mice bearing Ehrlich ascites tumors and treated with cortisol were investigated. Thymus-distinctive antigenicity and sensitivity to the cytotoxic effect of guinea pig serum and rabbit serum were significantly decreased, without change in reactivity to H-2 isoantibodies.*

Thymus cells of mice show several distinctive serological characteristics. The thymus cells of all mouse strains tested are sensitive to the cytotoxic effect of guinea pig serum (*1*); cells of some strains, such as SJL/J and A, possess a thymus-distinctive (TL) antigen that is absent from all other lymphoid cells (*2*). Normal thymus cells of other strains, such as C57BL, do not possess this antigen. Evidence has recently accumulated that the thymus may be constantly repopulated by stem cells from the bone marrow (*3*). Cells derived from the bone marrow or spleen of strain-A mice become TL-positive and sensitive to guinea pig serum upon repopulating the thymus of lethally irradiated recipients, of even TL-negative strains (*4*). It seems that stem cells entering the thymus may be constantly induced to acquire thymus-distinctive characteristics.

Since tumor growth (*5*) and administration of adrenocorticosteroid hormones (*6*) profoundly affect the thymus, their effect on the expression of thymus-distinctive characteristics was studied with inbred A, C57BL/6, and SJL/J mice. Pools of guinea pig and rabbit serums were obtained from random-bred animals. The isoantiserum used to detect the TL antigen was prepared by repeated intraperitoneal administration of thymus cells of the A strain to (BALB/c × C3H) F_1 hybrids (*2*). The isoantiserums used to detect H-2 isoantigens of the A and C57BL/6 strains were obtained following repeated intraperitoneal administration of spleen cells of the A and C57BL/6 strains to the reciprocal strains. The reaction of the isoantibodies with spleen or thymus cells was studied by a modification (*7*) of the cytotoxic test of Gorer and O'Gorman (*8*). The guinea pig serum used as source of complement was absorbed with murine tissues to remove its cytotoxicity to mouse thymus cells before being employed in the cytotoxic tests. The sensitivity of thymus cells to the cytotoxic effects of guinea pig and rabbit serums was tested by adding 25,000 thymus cells, suspended in 0.025 ml of normal saline, to 0.025 ml of serially diluted, unabsorbed, guinea pig or rabbit serum. A volume of 0.04 ml of cortisol acetate suspension (*9*) was administered subcutaneously. Fifty million Ehrlich ascites tumor cells were administered intraperitoneally. All the mice were maintained on regular Purina diet and water ad libitum; they were killed at various intervals after treatment, and the thymus and spleen cells were tested.

Within 18 hours of subcutaneous administration of 1 mg of cortisol acetate, the reactivity of A and SJL/J thymus cells with TL antibody disappeared completely (Tables 1 and 2). No TL antigenicity could be detected in the thymus cells within 6 days of administration of cortisol; on the 7th day some sensitivity to the TL antibody reappeared, and 1 day later the reactivity of the thymus cells returned to normal or became even slightly higher. The sensitivity of the thymus cells to